SPACE RADIATION SELECTION METHOD

Practice: Use this radiation method to select components for systems that operate in space.

Benefit: This practice describes a flight proven radiation component selection method. The method was used on the Advanced Communication Technology Satellite (ACTS). This spacecraft has operated in Geo-synchronous Orbit for 3.5 years (11/96). No failures with components have occurred in space due to radiation. The reliability was improved saving the project time and money. Similar methods have been used on other NASA projects.

Programs That Certified Usage: Space Shuttle Orbiter, Advanced Communication Technology Satellite, Viking, Voyager, Magellan, Galileo and various instrument programs.

Centers To Contact For More Information: Johnson Space Center, Lewis Research Center, Goddard Space Flight Center, Jet Propulsion Laboratory, and Marshall Space Flight Center

Implementation Method: When selecting components for use in a system, it is recommended that the method described in this practice be used for selecting your components. Radiation resistant components can be obtained from suppliers which have proven developments, manufacturing processes and process controls. It is very important that a survey of the manufacturer be performed to verify acceptable manufacturing processes and controls prior to the selection of a qualified supplier to obtain radiation resistant components. The following paragraphs describe the method.

Figure 1 shows the radiation hardness assurance program that was used on the ACTS Program.

The total dose radiation environment was defined: AE8 - Max model for trapped electrons; AP8 - Min model for trapped protons; and 2 AL August 1972 solar flares for 2-year mission. The data for this model was obtained from reference 9.

The dose depth curves as a function of shielding thickness for the spacecraft is shown in Figure 2. The data for this figure was obtained from reference 10.

The spacecraft shielding analysis was performed in three phases using the MEV dose profile (see reference 9) (MEVDP) shielding code: Phase I consists of constructing a computer model of the major structural elements of the spacecraft and determining the dose at various locations inside and outside the spacecraft; Phase II consists of modeling the various boxes situated at different locations in the spacecraft and determining the dose within each box; Phase III consists of modeling the circuit boards, device packages, and other structural elements within a box and determining the dose within the various radiation sensitive devices.

The Phase I radiation analysis results were: Mathematical model of spacecraft structure includes panels, bulkheads, fuel tanks, apongee kick motor (AKM), antennas, structural core, optical solar reflector and thermal blanket; radiation dose levels for equipment box locations range from 7.73E+05 rads to 2.94E+06 rads within the spacecraft structure; and dose levels identified potentially hazardous box locations early in the design phase.

The Phase II radiation analysis results were: GE Astro equipment and selected multibeam communication package (MCP) equipment modeled as hollow boxes; subcontractor-supplied boxes modeled as solids of uniform density including remaining MCP boxes which were analyzed by TRW/Motorola and reviewed by GE Astro; worst-case radiation dose levels calculated for GE Astro boxes range from 35 krads to 240 krads; d) worst-case radiation dose levels calculated for MCP boxes ranged from 9.4 krads to 40 krads; and e) shielding was provided by box walls, adjacent boxes and the spacecraft structure as described in Phase 1.

Table 1 shows the Phase II radiation analysis results for the GE and the MCF boxes.

Table 1 Radiation Analysis Results

A. GE BOXES	TWO-YEAR WORST-CASE DOSE LEVEL (IN KRADS)
Central Logic Processor	129.0
Attitude Signal ProcessoR	115.0
High-Rate Commands Detector	103.0
C-Band Command Receiver	129.0
KA-Band Command Receiver	129.0
Redundant Telemetry MODULE	123.0
Command Logic Demodulator	66.0
C-Band Beacon Transmitter	121.0
Ka-Band Beacon Transmitter	121.0
Uplink Fade Beacon	111.0
Power Supply Electronics	240.0 [1]
Central Logic Extender	35.0
Momentum Wheel Assembly	63.0
Array Drive Electronics	41.0 [1]
B. MCP BOXES	
Dual Power Converter	40.0
Motor Drive Electronics	39.5
If Module	13.6
Auto Track Receiver	9.4
Upconverter	12.5
Power Level Sensor	40.0
Driver Limiter Amplifier	40.0

[1] Four-year radiation dose level

The Phase III radiation analysis for the GE boxes showed: circuit boards, birtcher slides, connectors and packaging of critical radiation-sensitive devices located inside equipment boxes were modeled and added to the spacecraft model; radiation dose levels calculated at points within radiation-sensitive devices; and radiation hardness levels of semiconductor devices compared to calculated dose levels to determine additional-shielding requirements were obtained.

Similar work was done for the MCP boxes that showed: Phase II worst-case dose levels were determined for all boxes; radiation hardness levels were determined using TRW data, GE Astro data and data gathered by GE Astro from parts tested for the MCP boxes; and shielding requirements were determined based on Phase II dose levels and calculated radiation hardness levels.

For those parts that had to be radiation tested. The devices were either bought to the radiation environment (e.g. CD4000 series) or considered for radiation testing. Devices were radiation tested at wafer, diffusion, or inspection-lot levels: two devices per wafer - IRF-150, IRFF-130, IRFF9130; and eleven devices from each diffusion/ inspection lot, linear op-amps, wafer lot traceability, transistors, inspection lot traceability. During irradiation devices were biased to simulate worst-case operating conditions. Devices that were radiation tested used a Co-60 Gamma Ray source.

The Cosmic Ray environment was defined. Use was made of the environments developed by Adams of NRL. Most spacecraft manufacturers use this model to assess survivability and vulnerability of electronic systems. The following environment was used for the Cosmic Ray Analysis: 2 AL solar flares equivalent to August 1972; and) 90% worst-case-Galactic flux with uncertainties in flux data and solar activity applied. The one most often quoted by radiation hard suppliers is the 90% worst-case.

The cosmic ray effects that have been observed in semiconductors are: single event upset (SEU) - change in state of stored bit; single event latch-up (SEL) - high current condition with loss of stored data, inability to function, can burnout, must be powered off to remove condition, high temperature increases cross section and probability of hit. Single event burnout (SEB) - very high current condition due to secondary breakdown of parasitic transistor in power MOSETs caused by a heavy ion hit in gate oxide region.

The single event burnout of N-channel power MOSFETs is caused by: heavy ions induce second breakdown and burnout in power MOSFETs. The source-drain voltage threshold for this effect is approximately 50 ± 30% of rated breakdown voltage; threshold voltage decreases with increasing linear energy transfer (LET).

The cosmic ray analysis results are shown in table 2.

Table 2 Cosmic Ray Analysis Expected Effects.

PART TYPE	EXPECTED EFFECT
AD571	2.0e-05 Errors/Bit-Day, A/D converter
CA3089	No Effect
CD4000s	No Effect
CDP-1802D	No Effect
DAC-100	No Effect
GP-503	<2.0e-08 Errors/Bit-Day Level Shifter
H1508A	No Effect
IRF-150	Replaced With Irf-250. Operated @ 65 Vds-Rated @ 85 Vds
IRFF-130	Operated At 41 Vds-Rated @ 55 Vds (1% Duty Cycle) [1]
MM54C906D	No Effect
SG1525J	Negligible Effect
TA11370	<2.0e-08 Errors/Bit-Day Memory
ULS-2804H	No Effect
82S191	No Effect

[1] Burnouts over 2-year mission less than 1 part.

Four of the components were analyzed and found to have 2.6 upsets/30 days. Design requirement was allocated at 2.9 upsets/30 days so no additional changes were required.

The conclusions using this method to select components for space use were: radiation analyses were performed for all GE Astro boxes and selected MCP boxes; radiation analyses of MCP boxes designed by TRW and Motorola were reviewed by GE Astro; radiation testing was completed and hardness levels were determined for all device types; radiation shielding has been identified where required and incorporated into the designs per engineering change notices. The ACTS spacecraft has been operating in space for 3.5 years (11/96) with no problems caused by radiation.

Technical Rationale:

To ensure dependable and reliable electronic circuit designs, the radiation environment for total ionizng dose (TID) and single event effects (SEE) encountered at a specific height and orbital orientation during the space-craft mission must be determined. Such data is available from the literature, see references 1 to 7.

All electronic devices/components will experience two radiation related effects in space. The first, the TID effect is time dependent, and the second, SEE, depends on many factors and is independent of time. The two effects are addressed separately in design, and as such, this practice describes a method that has been used for selection of rad-hard components which can tolerate the effects produced by space radiation, within specified safe limits. The same procedure can be used no matter what the trajectory is [12, 13].

If the power is not turned off when lathup occurs in a power metal oxide semiconductor field effect transistor (MOSFET), the avalanche current within the prasitic silicon controlled rectifier (SCR) structure increases indefinitely to cause heating in the gate channel due to I^2R effects. This can lead to burn-out caused by a very high energy Cosmic Ray particle going through the transistor.

Another phenomenon associated with the power-MOSFET is gate-oxide damage called single-event-gate-rupture due to the presence of an extremely large electric field, which causes excessive force on the trapped charge. Both of these failure mechanisms are fatal to the component.

Impact of Nonpractice:

Failures of components encountered in space due to the use of non-rad-hard devices can lead to catastrophic results, which may lead to loss of the space system and possibly loss of life. Disregard for this practice can cost a program significant resources and make the difference between success and failure of a space mission.

References:

1. David M. Long, "Hardness of MOS & Bipolar Integrated Circuits, "IEEE Transactions on Nuclear Science, Vol. NS-27, No. 6, December 1980.

2. E.G. Stassinopoulos, "Radiation Environment in Space, "IEEE NSPEC Short Course, July, 1990.

3. George C. Messenger, and Milton S. Ash, 'The Effects of Radiation on Electronic Systems, "Van Nostrand Reinhold Company, New York, NY, 1986

4. "Space Station Ionizing Radiation design Environment, "NASA SSP 30512 Rev. C, June 1994

5. "Space Station Ionizing Radiation Environment Effects Test and Analysis Techniques, "NASA SSP 30513 Rev. B, June 1994.

6. "Space Station Program Natural Environmental Definition for Design," NASA SSP 30425 Rev. B, February 1994.

7. "Goddard Space flight Center Preferred Parts Test," NASA GSFC PPL-21 Notice 1, May 1996.

8. "Independent Readiness Review Supplement," Astro-Space Division, General Electric Company, Contract NAS3-23790, June 1992.

9. "MEV Base Profile" (MEVDP) Shielding Code, Astro-Space Division, General Electric Company,1975 (?).

10. "ACTS Flight system Performance Specification," PS-262352, astro-Space Division, General Electric Company, Rev. U, March 1989.

11. ACTs System Operation Handbook, " ACTs 611.01, NASA September 1993.

12. "Component and Spacecraft Verification Specification Neio Millenium Deep Space Mission No. 1," Spectrum Astro Inc., JPL Contract No. 960446, January 1996.

13. C. Barnes and L. Selva, "Radiation Effects Review: GaAs MMIC devices and circuits, "JPL D-13972, September 1996.

14. Kenneth A. LaBel et al., "Commercial microeletronics Technologies for Applications in Satellite Radiation Environment, "IEEE Aerospace Applications Conference, February 1996.

15. Kenneth A. LaBel and Michele M. Gates, "Single Event Effect Mitigation from a System perspective, "IEEE Transactions on Nuclear Science, April 1996.

FIGURE 1 Radiation Hardness Assurance Program

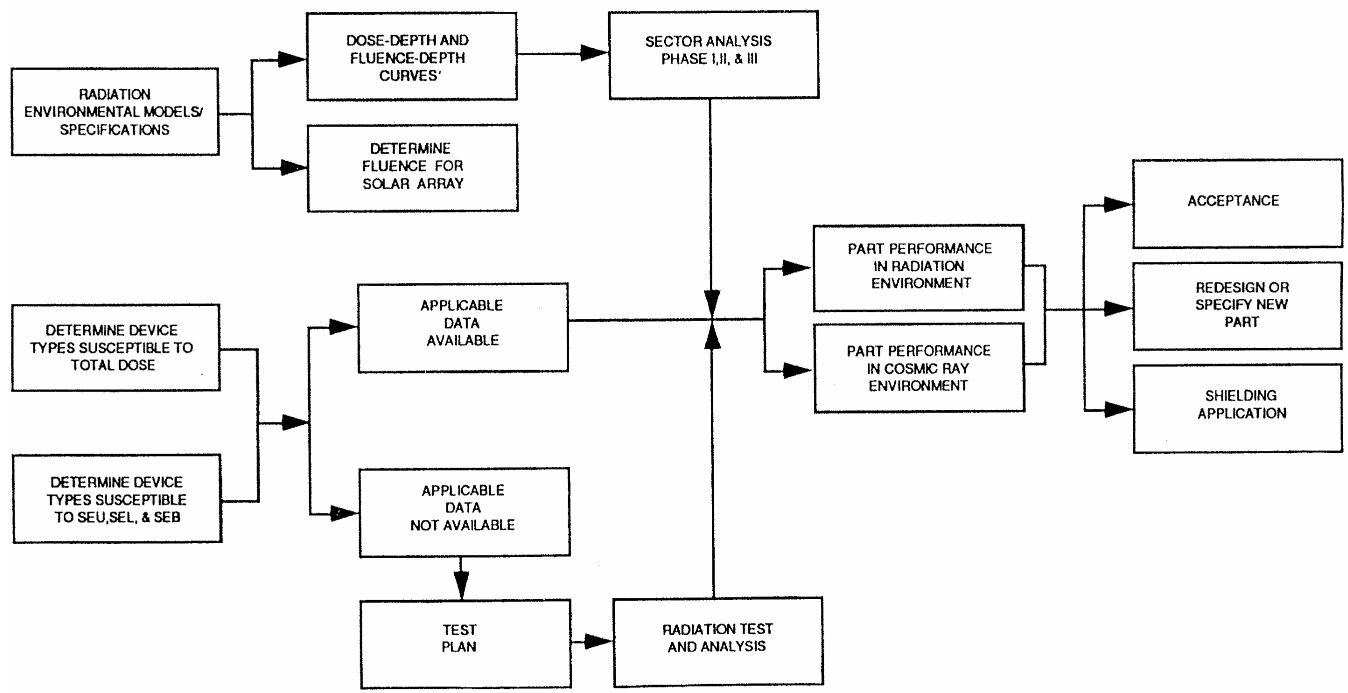

Figure 2 Dose-Depth Curves